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ENGINEERING CONSULTANTS

PaveState

A TOOL for viewing pavement Structural CHARACTERISTICS

PaveState

Understanding the structural state of pavements their distress mechanisms, future performance and maintenance and/or rehabilitation requirements

Collected condition data and structural evaluations can now be presented in any desired form

i. in the office, desktop viewing properties of the entire network, or

ii. In the field, at each test position along the road during inspections or

iii. during maintenance/rehabilitation, using the visual display of a GPS enabled smartphone or tablet.

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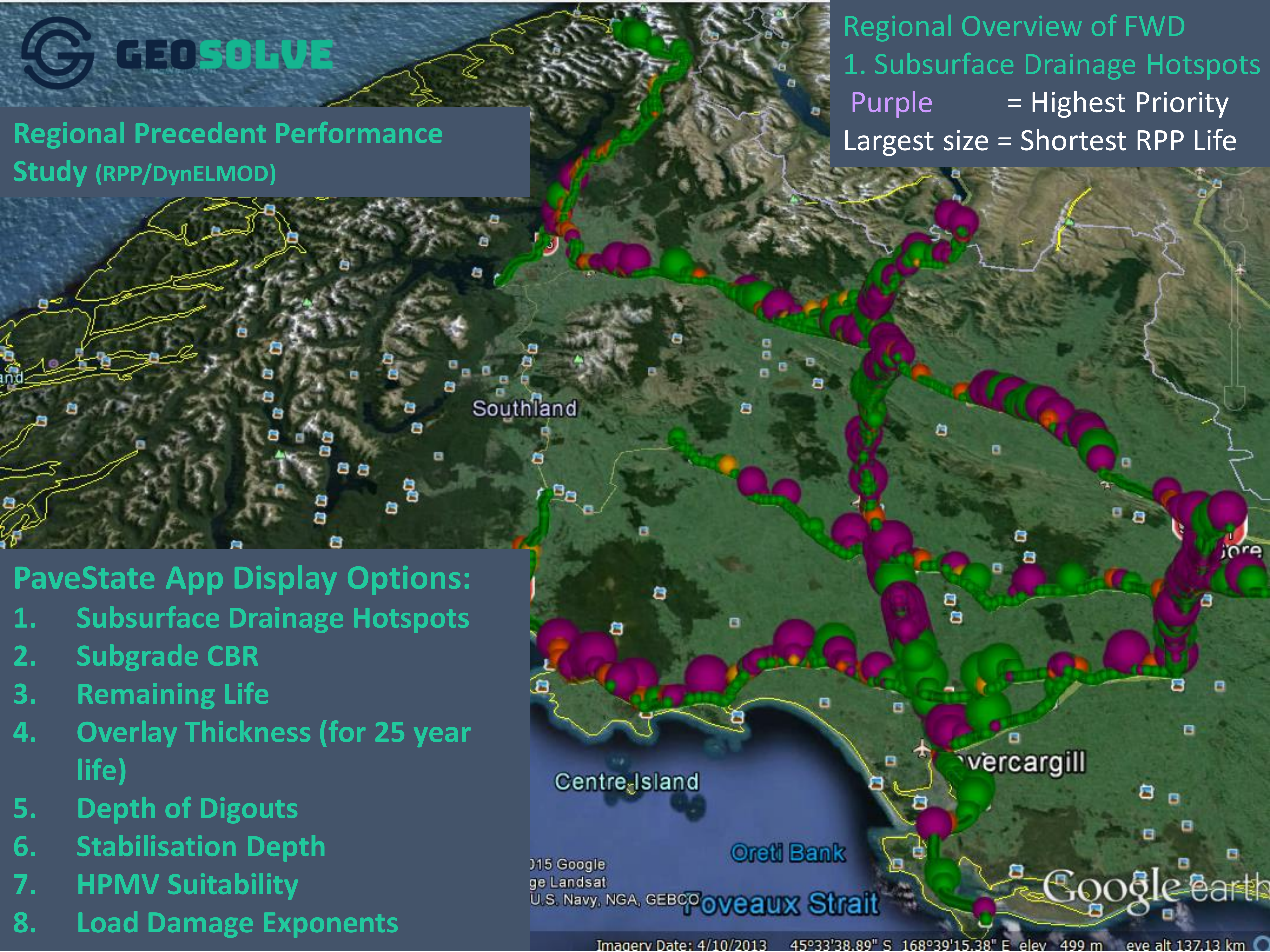
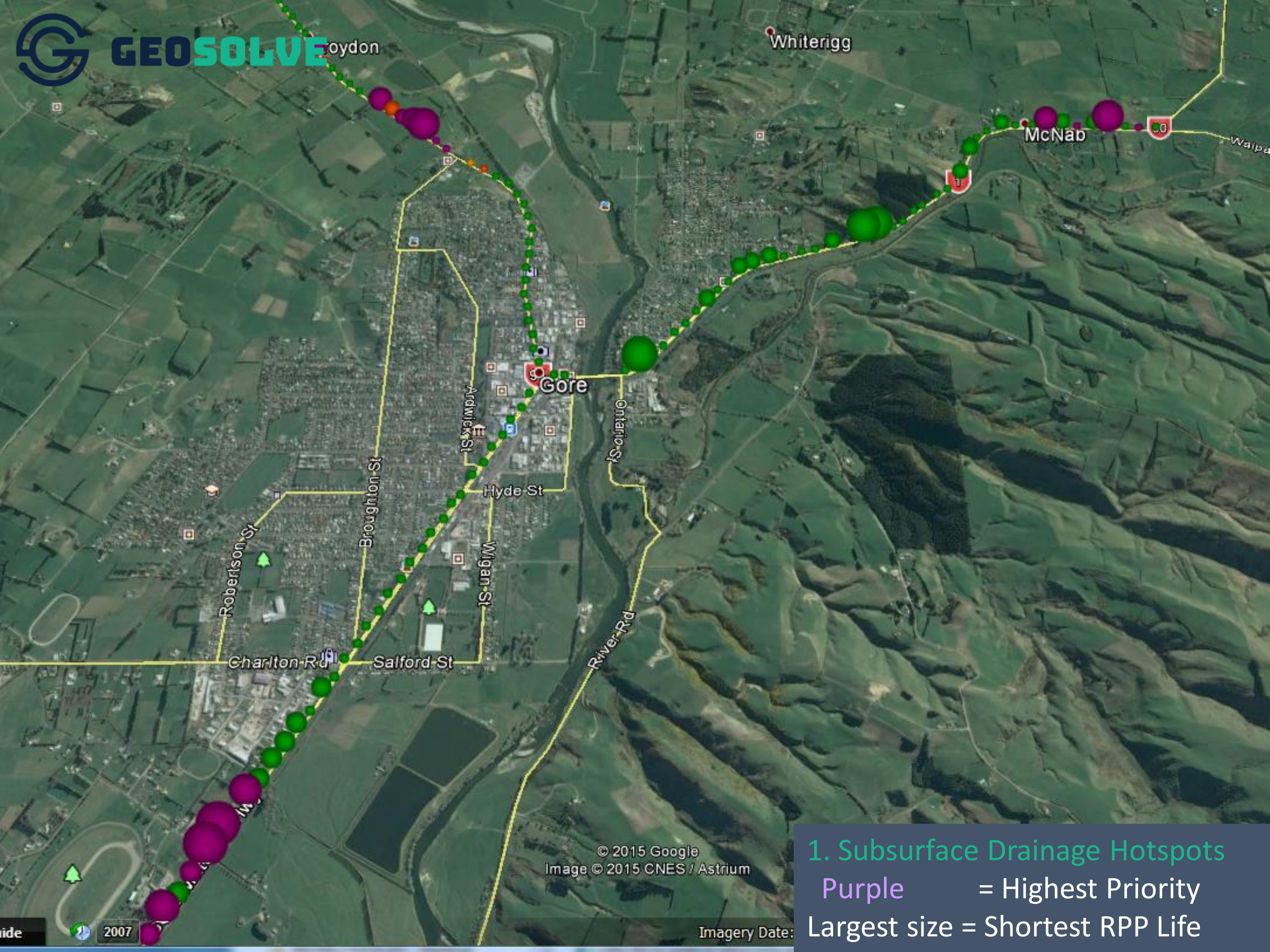
Regional Precedent Performance Study (RPP/DynELMOD)

Regional Overview of FWD
1. Subsurface Drainage Hotspots
Purple = Highest Priority
Largest size = Shortest RPP Life



PaveState App Display Options:

1. Subsurface Drainage Hotspots
2. Subgrade CBR
3. Remaining Life
4. Overlay Thickness (for 25 year life)
5. Depth of Digouts
6. Stabilisation Depth
7. HPMV Suitability
8. Load Damage Exponents



1. Subsurface Drainage Hotspots

Purple = Highest Priority

Largest size = Shortest RPP Life

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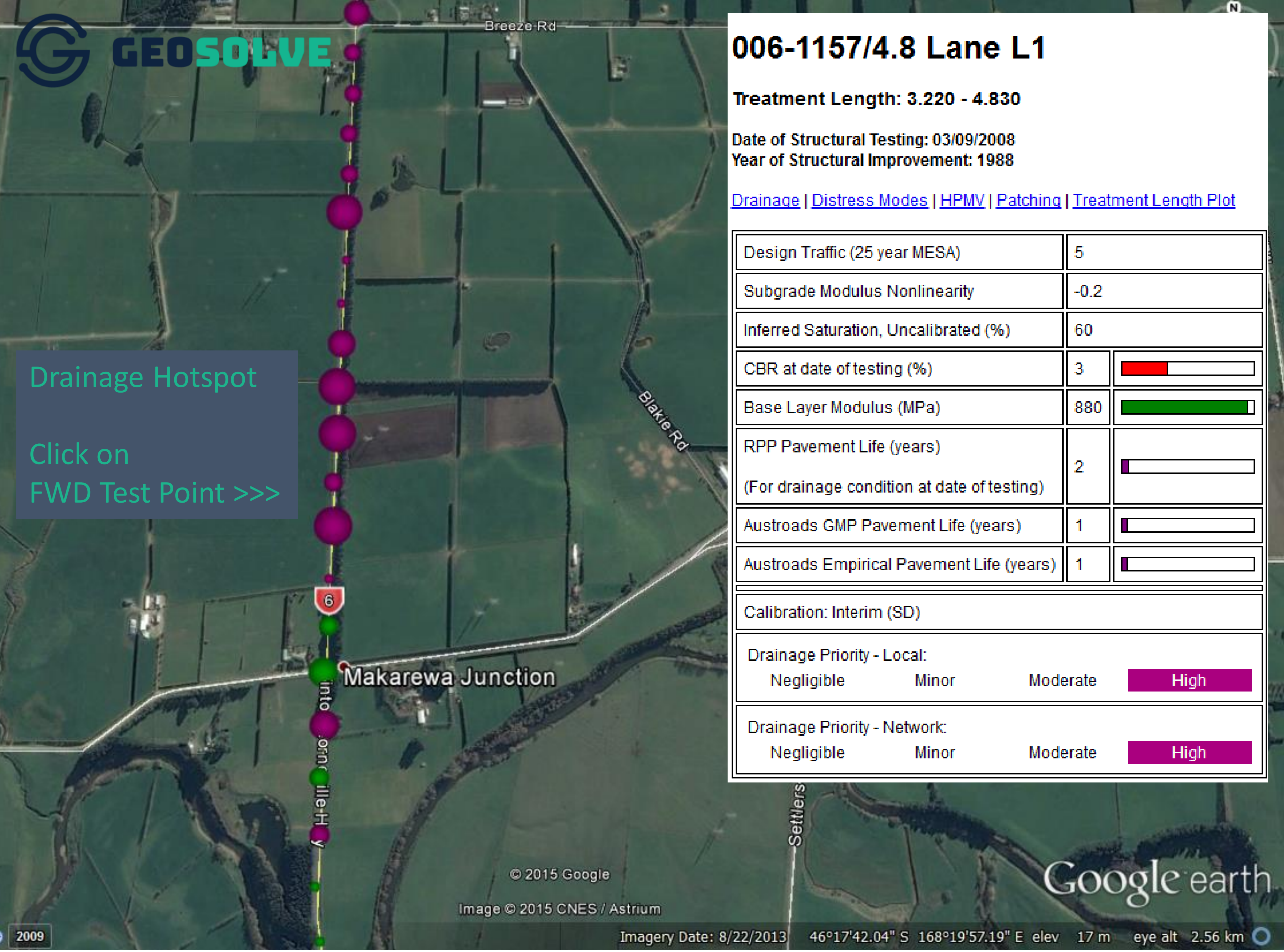

Drainage Hotspot

Click on
FWD Test Point >>>

006-1157/4.8 Lane L1

Treatment Length: 3.220 - 4.830

Date of Structural Testing: 03/09/2008
Year of Structural Improvement: 1988

Drainage | Distress Modes | HPMV | Patching | Treatment Length Plot

Design Traffic (25 year MESA)	5	
Subgrade Modulus Nonlinearity	-0.2	
Inferred Saturation, Uncalibrated (%)	60	
CBR at date of testing (%)	3	
Base Layer Modulus (MPa)	880	
RPP Pavement Life (years) (For drainage condition at date of testing)	2	
Austroads GMP Pavement Life (years)	1	
Austroads Empirical Pavement Life (years)	1	
Calibration: Interim (SD)		

Drainage Priority - Local:
Negligible | Minor | Moderate | **High**

Drainage Priority - Network:
Negligible | Minor | Moderate | **High**

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Content

- What is PaveState,
- Overview of Pavement Structural Life,
- Structural Life, Distress Modes and Terminal Conditions,
- Operation of PaveState,
- PaveState outcomes / deliverables,
- PaveState uses,
- Short demonstration.

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What is “PaveState”?

A GIS smartphone app, developed to support pavement site inspections for assessing maintenance or rehabilitation requirements, and enabling critical decisions that are best made in the field, ie is maintenance practical (just resurfacing) or should this treatment length be structurally rehabilitated?

PaveState enables a pavement designer /asset manager/maintenance staff to view a graphical display of the road at his/her current location showing:

- positions where structural information has been obtained (eg FWD or TSD deflections, test pits, Scala probes etc) and,
- relevant pavement structural parameters, such as structural indices, CBR, drainage potential, potential distress modes and associated remaining life (when distress modes are likely to become terminal).

This enables optimised maintenance scheduling and verification or fine tuning of the forward work programme for rehabilitation.

Overview of Pavement Structural Life

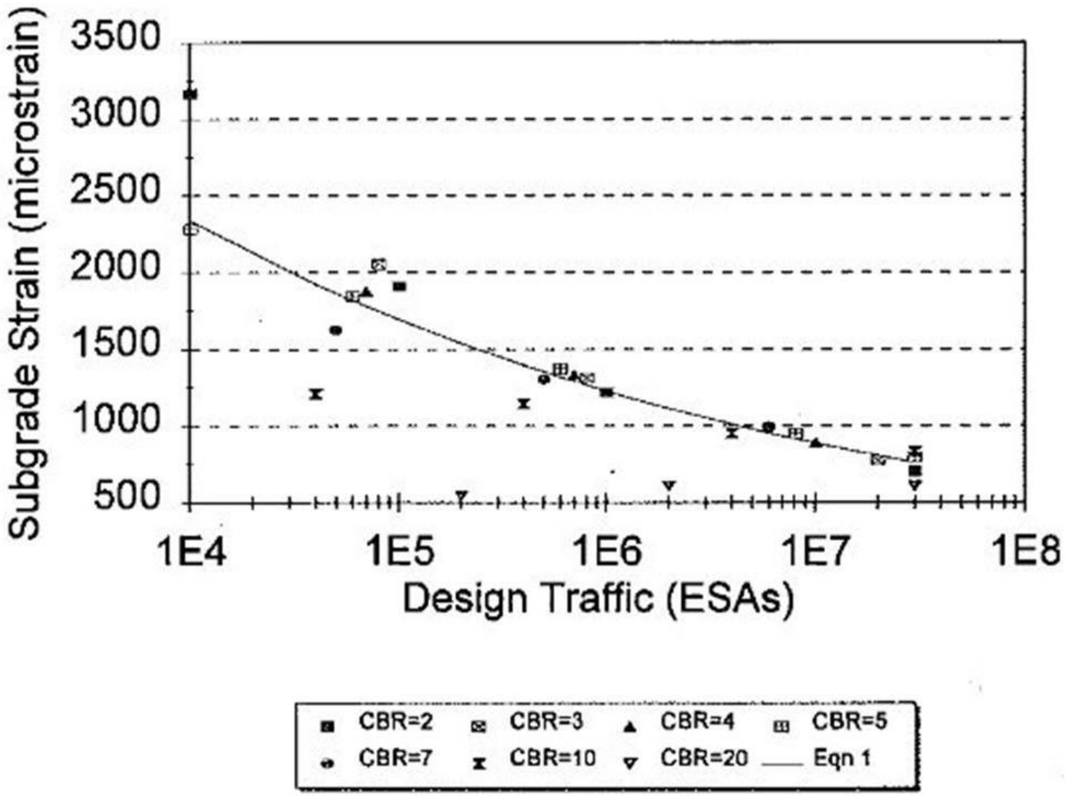
Pavement 'Life' (Remaining Life), as discussed in this presentation relates to the 'Resurfaced' Structural Life of a pavement, given the layer configuration of the particular treatment length at the time of FWD testing, as far as the pavement structural capacity is concerned, and assumes the pavement surface is planned to be maintained and periodically resurfaced to a near-new condition (with minimal accompanying change in structural capacity) and maintenance/resurfacing practices will continue to be applied in the future, as they have been in the past. Life may be qualified with "Structural Life" where there is also reference to surfacing life, to avoid any ambiguity.

Overview of Pavement Structural Life

Economic Life is used where the trigger for rehabilitation is excessive maintenance costs, and in practice this is likely to mean that multiple distress modes will combine to trigger intervention. Total Life is of less relevance to this study of unbound granular pavements as it applies particularly where there are bound layers, and is the life from new or from time of last structural rehabilitation if regular maintenance and resurfacing is carried out.

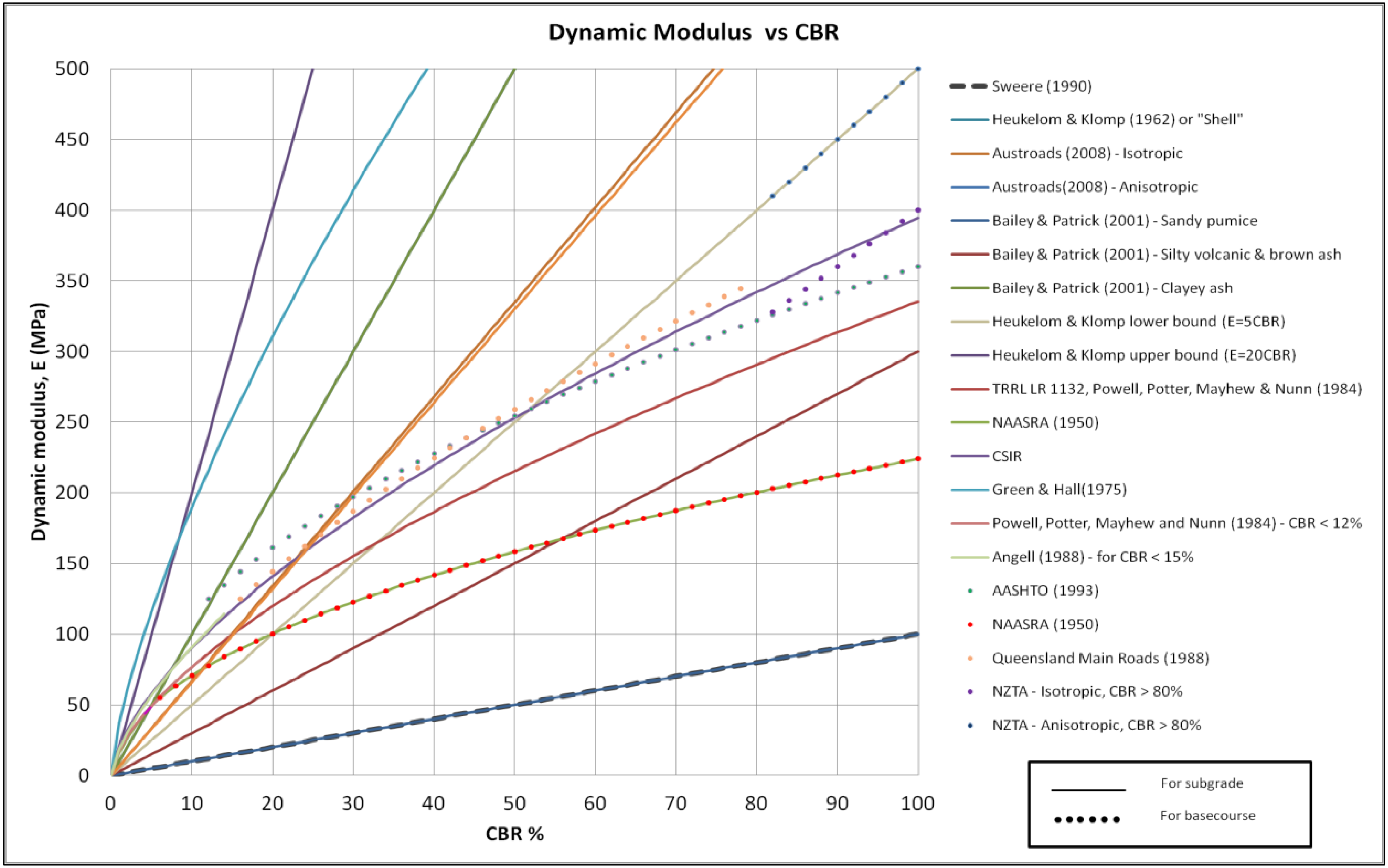
Austroads Subgrade Rutting Model

The base data used for the Austroads rutting model used a total of 24 observed road sections and concluded that the life of unbound granular pavements related to vertical strain at the top of the subgrade, assuming the subgrade modulus was given as 10 times the CBR.

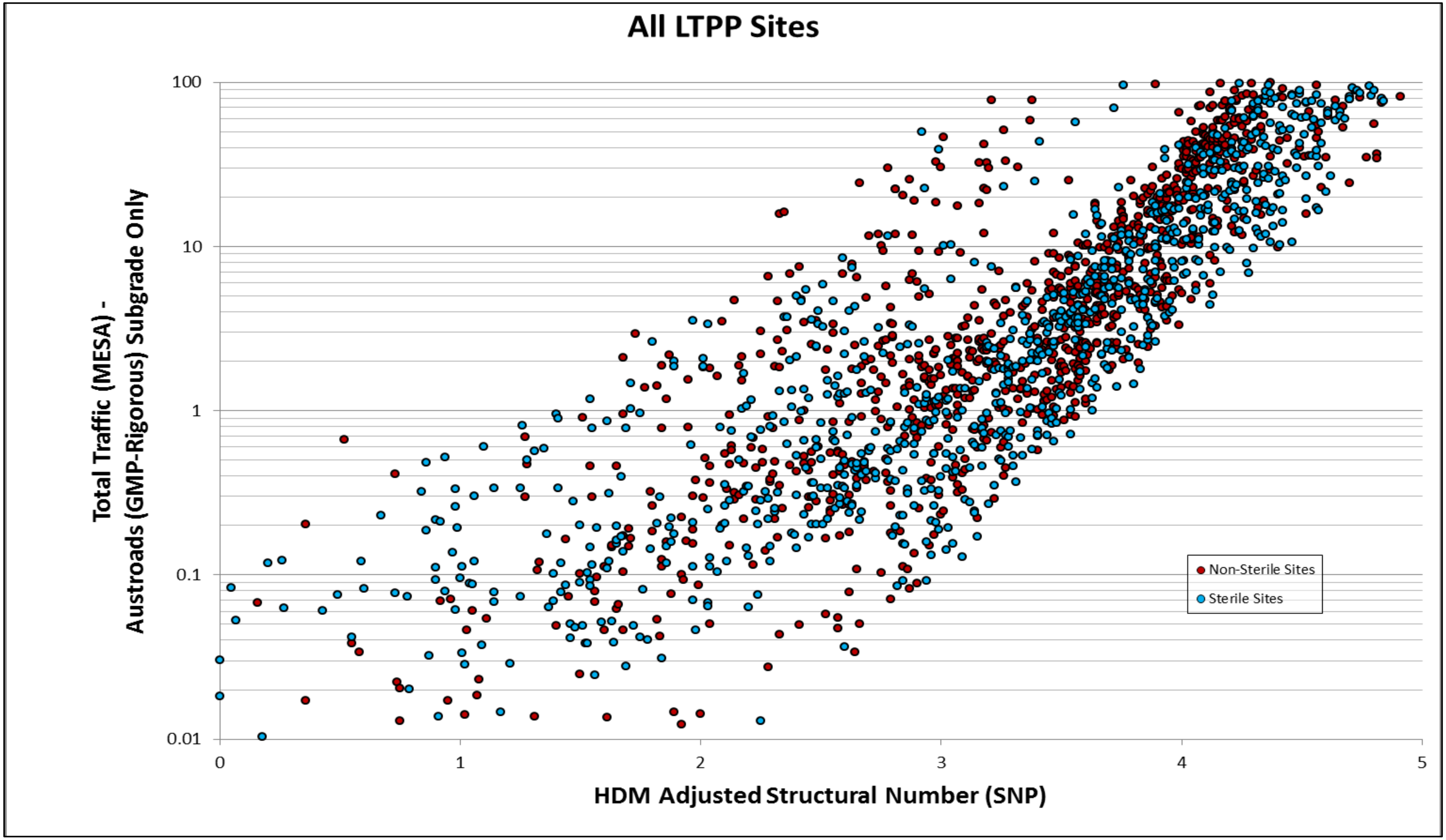


Original data used to derive AUSTROADS subgrade strain criterion (Youdale 1984)

CBR – Modulus "correlation"



GEOSOLVE Austroads vs SNP "correlation"



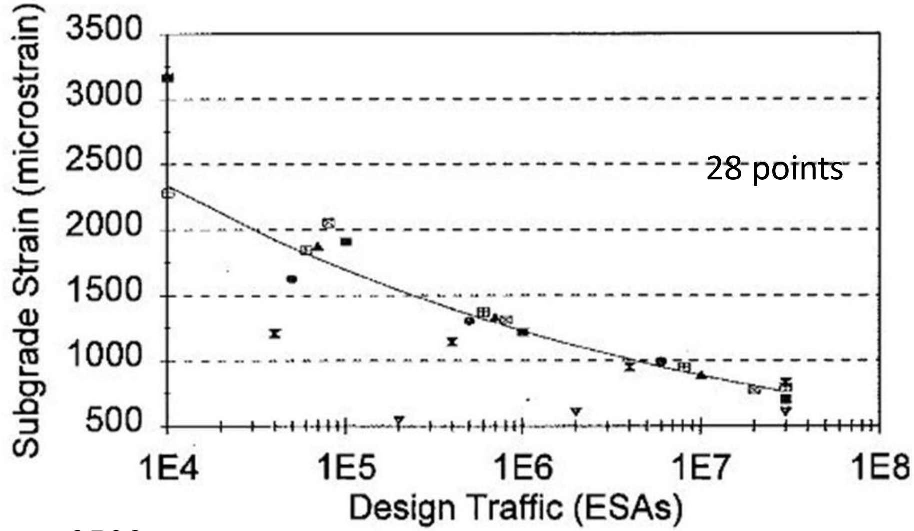
Austroads vs NZ Regional Model

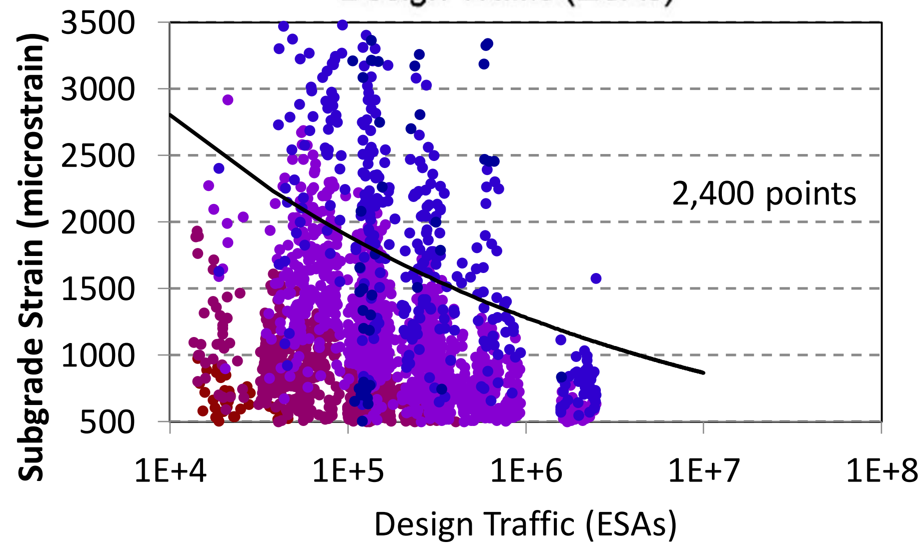
These graphs compare the Austroads model (24 points from the 1984 report) - top right

with

NZTA's Region 14 strains (2,400 points that have already been rehabilitated and 90,000 current points) have been rigorously back-calculated from deflection bowls, rather than estimated from CBR. The best fit 90 percentile curve is shown at bottom right

It is important to note that the concept is identical, for both approaches. It is only the database source region, size, and accuracy of measurement (and hence reliability) that has changed.





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Structural Life, Distress Modes and Terminal Conditions

As repeatedly emphasised by Patrick[1], [2] and others, it has been demonstrated that few New Zealand pavements attain a terminally high severity of rutting because regular maintenance as well as pre-sealing repairs, limit rut depths, therefore roads are more likely to be rehabilitated for basic economic reasons, usually because the net present value (NPV) of predicted future maintenance costs exceeds rehabilitation cost.

For any distress mode, the traditional method of predicting pavement life has been to observe pavement performance in relation to mechanistic parameters eg subgrade strain as adopted by Austroads, but that model dates back several decades, so greater use of current technology may warrant consideration.

Regional Precedent Performance of Pavements

With more than 20 years of Falling Weight Deflectometer testing carried out in New Zealand, there are now over a million FWD test points on record, many of which relate to pre-rehab testing, ie treatment lengths in a state of terminal distress. Conventional back-analyses of the FWD data allow far more accurate quantification of strain with many more relevant data points, than the minimal number of strains approximated from the CBR tests adopted by Austroads from the 1984 study.

Hence rather than limit pavement design criteria to those from one set of Australian roads, research for the Transport Agency has focused on obtaining pavement design criteria for each of the Regions in New Zealand, appropriately reflecting the local climate, materials, specifications, construction and maintenance procedures.

This study of the Regional Precedent Performance of Pavements has been regarded as ground breaking by its international reviewer, because of the detailed QA and large amount of interpreted FWD test maintained for each Region.

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Regional Precedent Performance of Pavements

- The strength of the RPP study is that it defines critical values for deformation or fatigue parameters in each mature network of unbound granular pavements, and these can be inherently inclusive of all possible structural distress modes if the analysis is done for stresses and strains in all layers Therefore, RPP analysis can be utilised to generate either a series of specific fatigue criteria that will result in a terminal condition for any layer (including the surfacing), or the life until a terminal condition is reached on economic grounds. Whichever mode applies, the end result is a trigger for rehabilitation, when running the Forward Work Programme model. Using these concepts allows the RPP model for pavement life prediction in terms of distress modes[3] to be adapted to incorporate the following categories:
  - **Surfacing distress modes**
  - **Structural distress modes**
  - **Economic triggers**

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Distress Modes and Terminal Conditions

Surfacing distress modes

1. seal deformation (more likely as multiple seal layers accumulate)
2. flexure (cracking in seal or thin AC)
3. Seal flushing

Structural distress modes

1. aggregate rutting (basecourse or sometimes subbase)
2. shallow shear (shoving) of basecourse or subbase
3. potholing- aggregate instability/excessive water in unbound granular layer(s)
4. aggregate degradation
5. cracking (conventional, bottom up) of bound layers
6. flexure (top down cracking) of bound layers
7. subgrade rutting
8. subgrade shear
9. roughness progression

Economic triggers

1. excessive maintenance costs for the surfacing
2. excessive maintenance costs for the structural layer(s)

Distress Modes
– DynELMOD Model

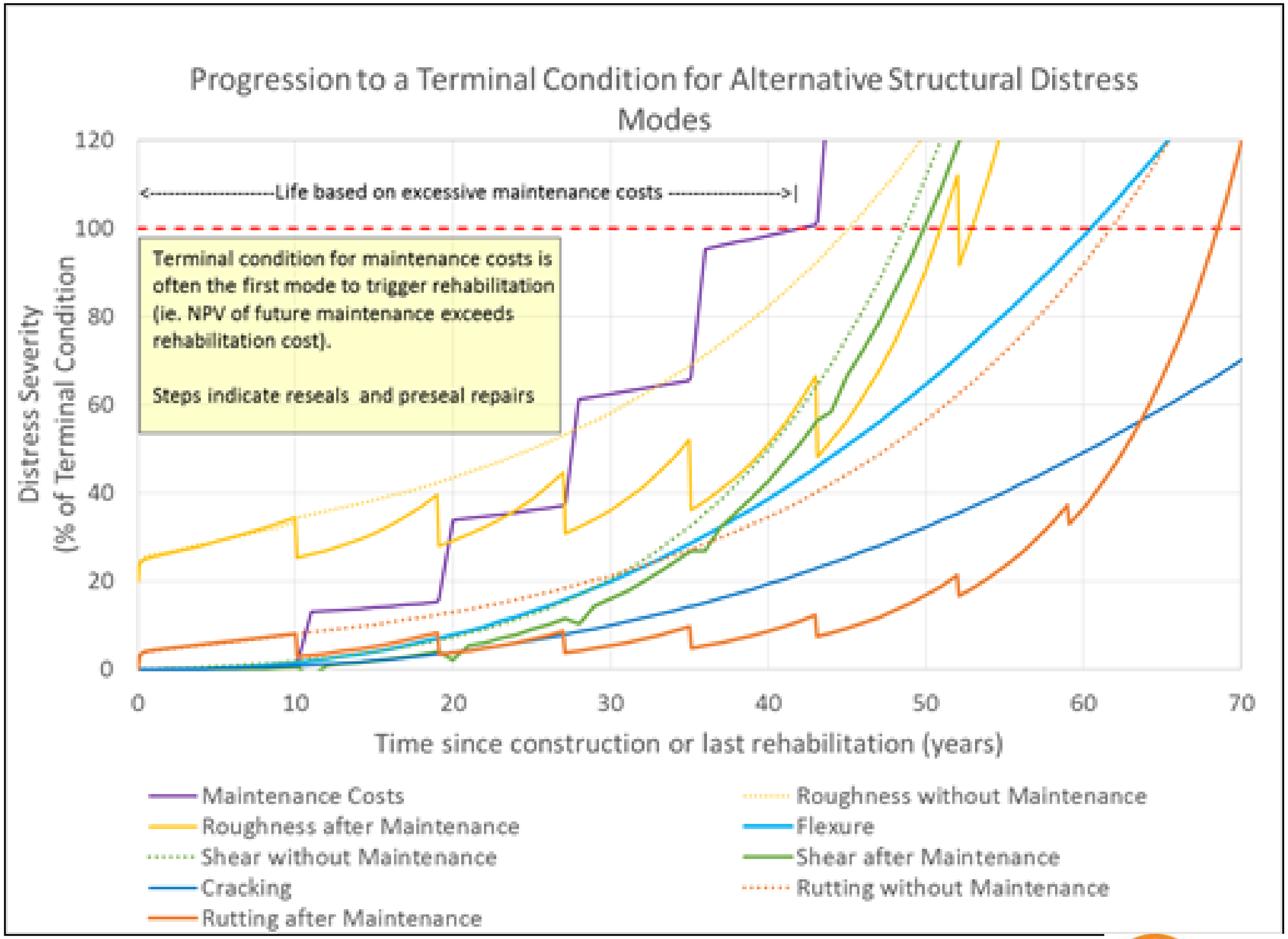
- Primary structural data is from RAMM, test pit logs, CBR & FWD data, plus an extensive database of the corresponding relevant structural evaluations using multi-layered elastic models.
- FWD records include not only peak deflections but also the much more detailed characterisation available from the full time histories for each geophone and now an increasing variety of sensors being explored (pavement analyser).

Structural Life, Distress Modes and Terminal Conditions

The maintenance costs will often be caused by the cumulative deformation induced by two or more different distress modes in combination (e.g., predominantly roughness and shear instability would be the inferred modes in the example following). If maintenance costs are predominantly due to non-structural modes, then the maintenance cost progression model may not be relevant, but in that case resurfacing would be required rather than structural rehabilitation.

This set of terminal conditions, may be used to systematically evaluate pavement life for each distress mode with the minimum life determining the critical (governing) mode, as illustrated conceptually below.

Structural Performance Model



Structural Performance Model

The steps represent reseals and pre-seal repairs. Time intervals between reseals are likely to decrease progressively.

Patrick considers that in some cases, these can cycle almost indefinitely with little ongoing increase in rutting or roughness, accompanied by little or no increase in maintenance cost (similar to the perpetual pavements concept for bound layers). However seal instability should eventually develop (encompassed by the shear mode in the above model), and if not, shear instability from basecourse degradation is probably inevitable.

For multiple seal layers, while instability may develop within the surfacing, the solution is classed by Gray[4], and others as rehabilitation treatment rather than re-surfacing as the cheapest measure may be to cement stabilise the seal into the basecourse (recycling), ie producing a structurally stiffer pavement as well as rehabilitating the surfacing.

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Structural Life, Distress Modes and Terminal Conditions

There are of course many additional distress modes (over 20 identified by Dawson[5], [6]).

Some of these, e.g. foundation settlement (consolidation at depth due to surcharge) and foundation shear deformation, may have been instigated by pavement surcharge and can therefore trigger structural rehabilitation but they are not directly related to traffic loading and are hence not considered in the RPP structural model.

Similarly, the other various forms of surfacing distress are not considered as they do not require structural rehabilitation.

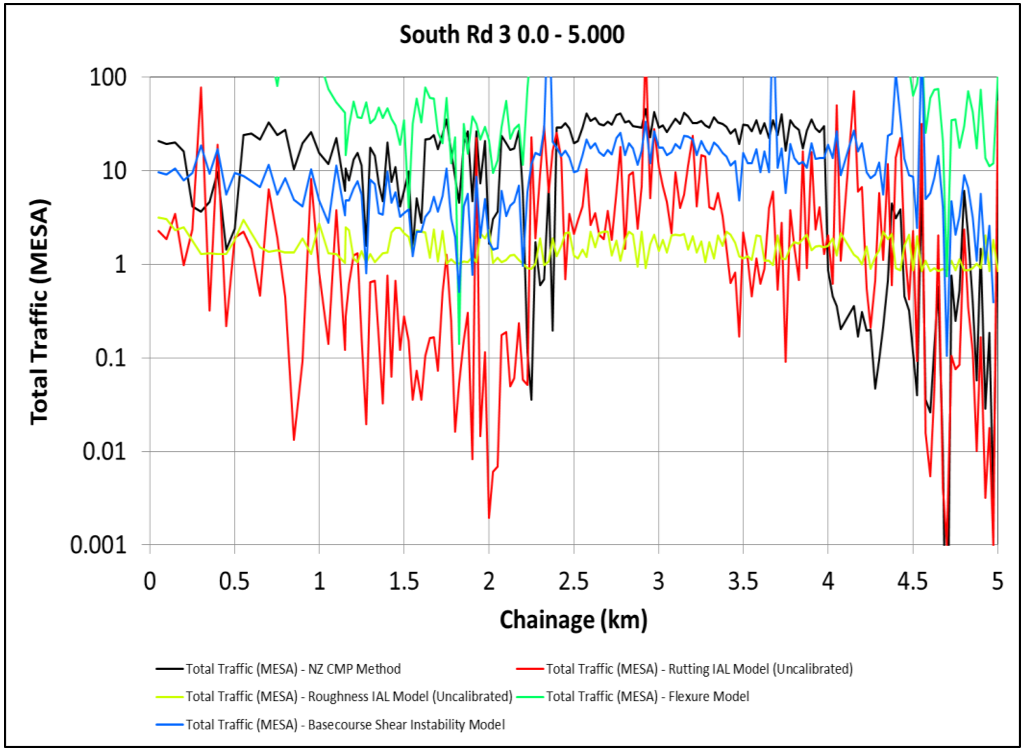
Predicted Life by Distress Mode

- For each individual road or treatment length, model determines which mode of distress occurs first for each test point.

- **Legend**

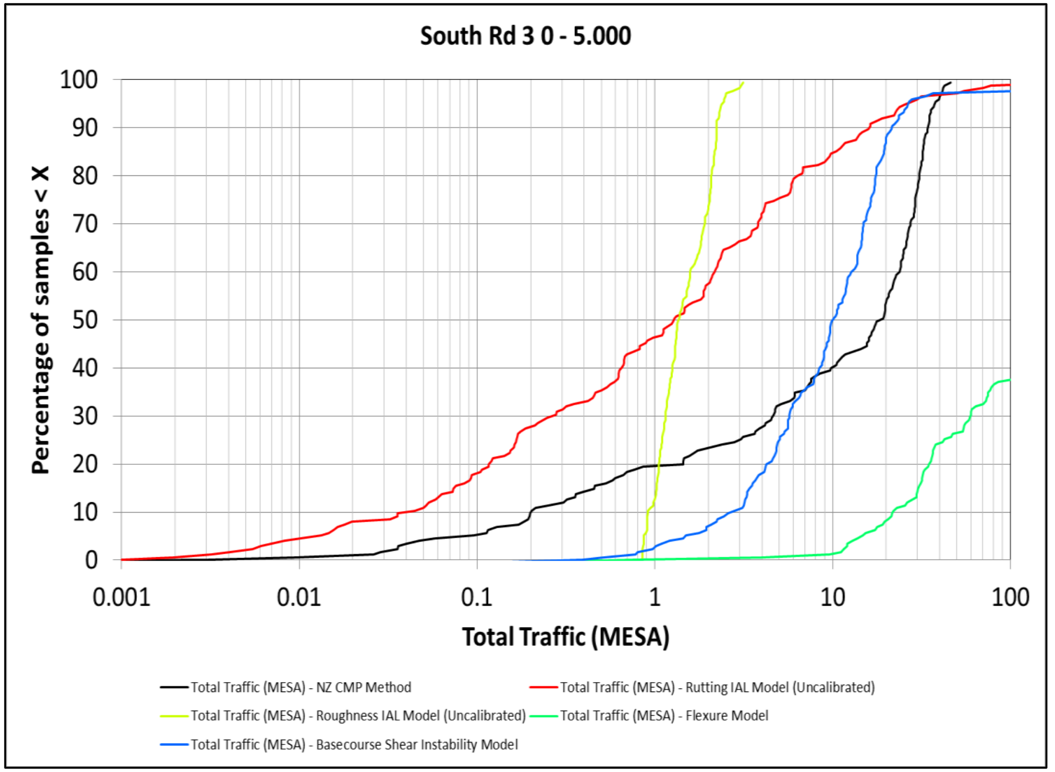
Flexure
Excessive maintenance costs
Shear
Roughness
Rutting

- Calibration preferable for each region.



Predicted Life by Distress Mode

- For each individual road or treatment length, the cumulative plot allows ten percentile life to be readily assessed along with principal distress mode.



- **Legend**

Flexure

Excessive maintenance
s

Shear

Roughness

Rutting

- 10 percentile life => 0.04 MESA

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Distress Modes and Terminal Conditions

Moving from a single fatigue criterion for unbound granular pavements to 5, then more recently to 10 or more has been an evolving process during the RPP study. With successive pavement engineers from different regions providing feedback, “exceptions” (where the reality check was inconsistent with the model) became evident, requiring refinement or the addition of entirely new stress/strain or other deformation criteria in the model. Refinements continue but for the regions which have been evaluated, its reliability is a major advance on dTIMS as far as rehabilitation is concerned.

Using the RPP estimate of economic life in conjunction with modelling the other structural distress modes (fatigue related) allows asset managers to substantially extend the number of years for which modelling of a Forward Work Programme can be reliably projected, from 2 or 3 years to a decade and considerably longer if ball park estimates are required.

Sources of PaveState Information

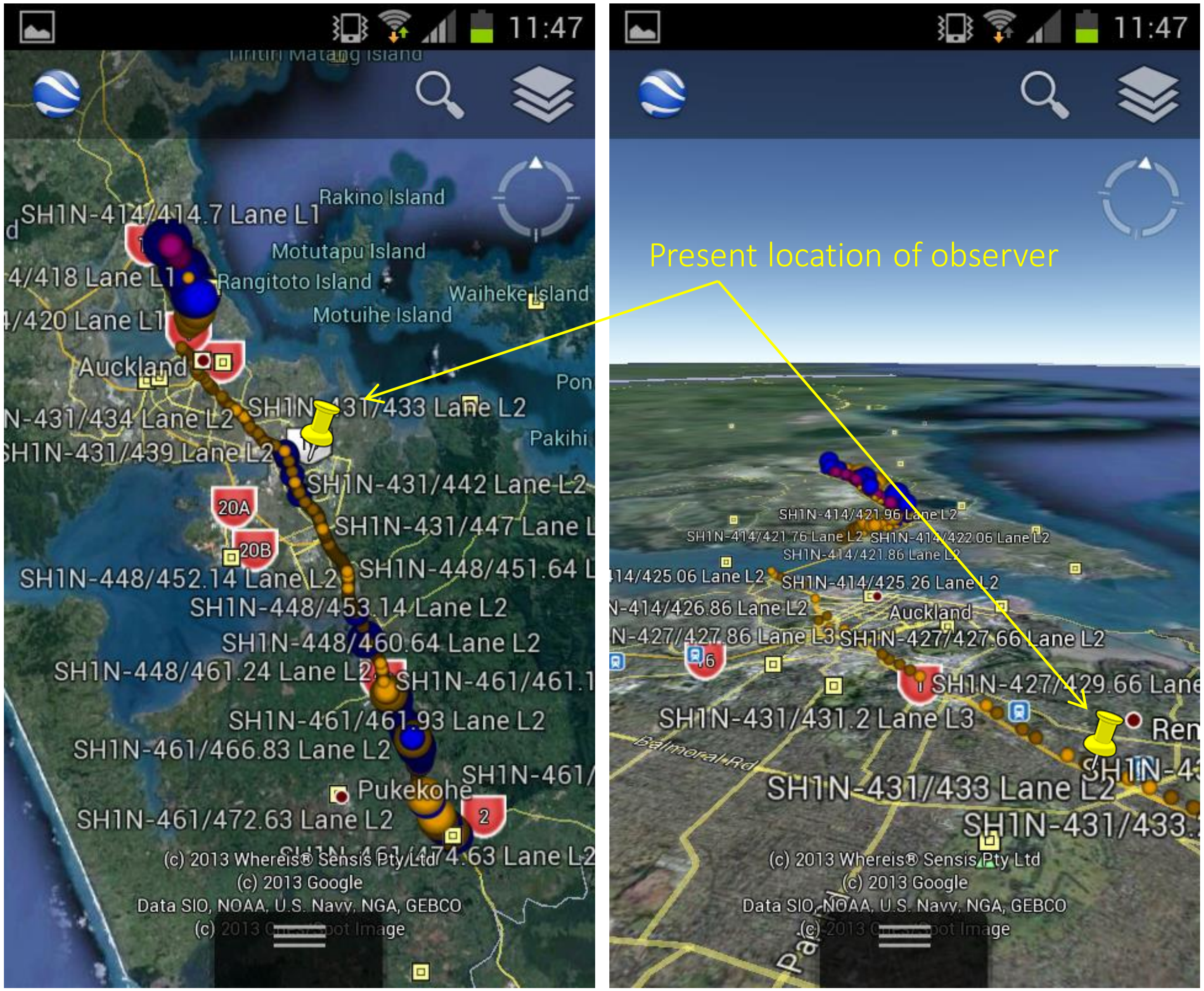
PaveState generates its output files using a variety of data sources. The foremost among these is ELMOD (Evaluation of Layer Moduli and Overlay Design) widely recognised pavement analysis software by Dynatest. This package accommodates non-linear subgrade moduli which are exhibited by the majority of New Zealand soils.

DynELMOD: Is an adaption of ELMOD to incorporate additional sensors and inclusion of (i) dynamic characteristics at each test point (ii) the RAMM (Road Asset and Maintenance Management) database and (iii) links to in-house file information (test pits, penetration tests, layer properties).

http://www.dynatest.com/software/elmod.aspx

Additional sensors are being explored progressively to ensure that the rapidly advancing technology changes are being utilised to the maximum extent practical.

Potential Pavement Life Display – (colour coded)



SH1N-414/417.3 La...

Potential Life and Distress Mode

Design ESA (25 years)	2.20E+06	
Total Life, Rutting* (years)	24	
Total Life, Roughness* (years)	50	
Total Life, Flexure* (years)	4	
Total Life, Shear* (years)	13	
Total Life, Governing IAL* (years)	4	
Potential Total Life for the most critical distress mode (years)	4	
Test Date	21/08/2012	
*Note: models are uncalibrated for this site.		

Distress Mode Least Life

Shear Instability | Flexure | Cracking | Roughness | Rut

Potential Total Least Life of Pavement (years)

> 25 | 25 > 10 | 10 > 5 | < 5

PaveState - Operation

DynELMOD takes relevant pavement condition data, from deflection testing equipment (FWD, TSD, Benkelman Beam etc), geotechnical testing (Scala penetrometer, boreholes and test pit information) which may be stored in RAMM.

PaveState then uses Microsoft Windows PC software to convert RAMM condition data in Excel Spreadsheet format into a ‘Google Earth’ KML output file.

Output file can then be viewed in the field on any Google Earth capable device (including tablets, smartphones, laptops, net-/ultra-books) running almost any operating system –(Android, Apple iOS or Windows)

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PaveState Outcomes

A variety of parameters may be displayed, most commonly:

- ✓ the location of the observer (using smart phone or other device's inbuilt GPS),
- ✓ the locations of all adjacent FWD tests, (most recent, but also going back 20 years for some areas)
- ✓ what distress mode is predicted to prevail eventually at each FWD test point,
- ✓ the consequent life of the pavement (remaining life) before that distress mode reaches a terminal state and,
- ✓ an evaluation of whether maintenance/resurfacing is viable, or should this treatment length be renewed.

Potential Pavement Life - (on PC)

Details – What You Get

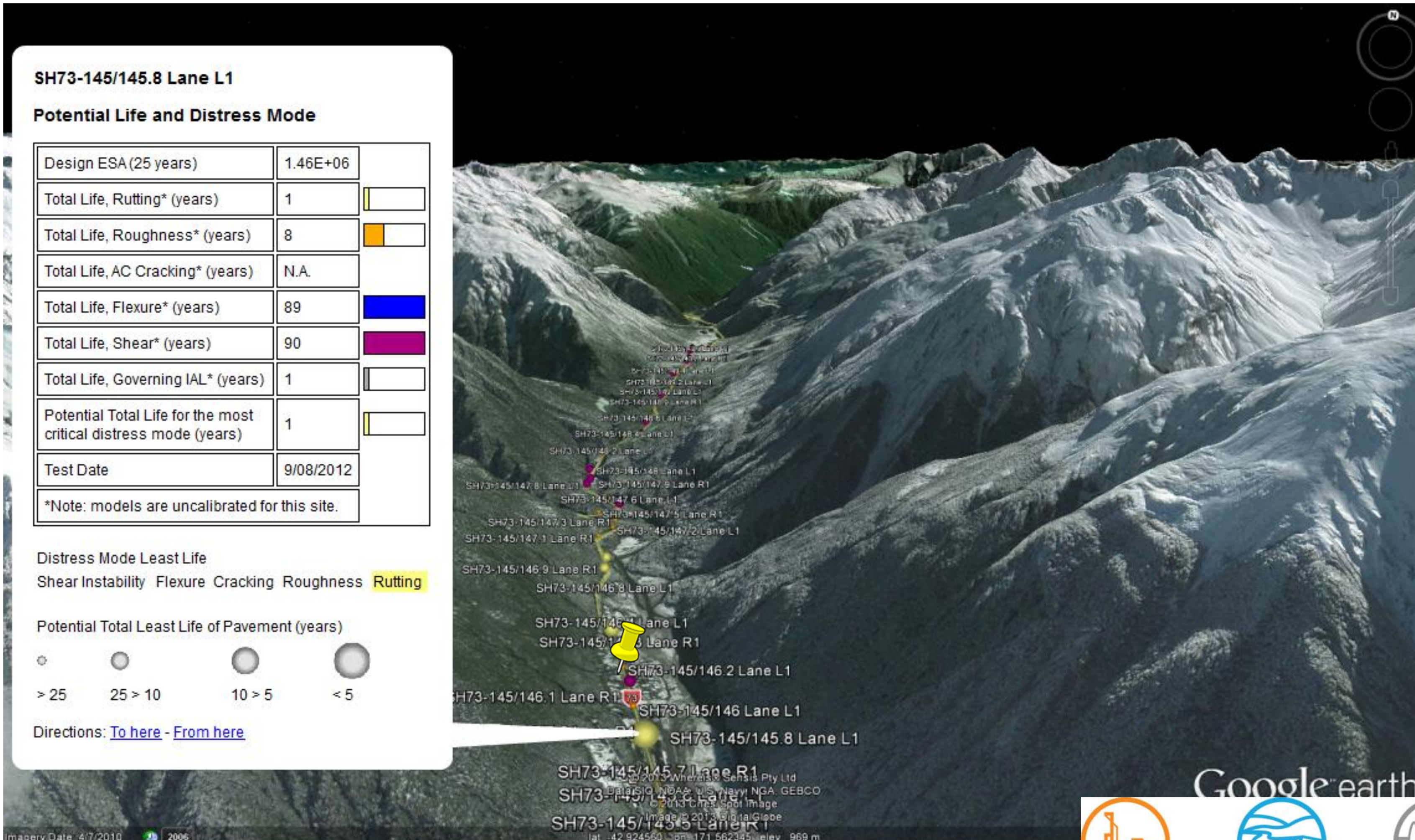
Marker symbols with colour coding:
Markers are generated at the geographical location of each FWD test point, and marker colour and size give the user an instant snapshot of the pavement parameters at each point.

For example, marker size is usually scaled to indicate the magnitude of the remaining life, and colour is used to discern the specific distress mode that is predicted to be critical, ie the mode that will first result in a terminal condition. (Life beyond 25 years is academic only, but nominal values are still shown for relativity.)

Clicking on a single marker point will bring up an itemised report, which will reflect the output fields the user has chosen.

In any case, the report will provide actual recorded test result data for in-depth analysis.

Potential Pavement Life (Arthur's Pass)

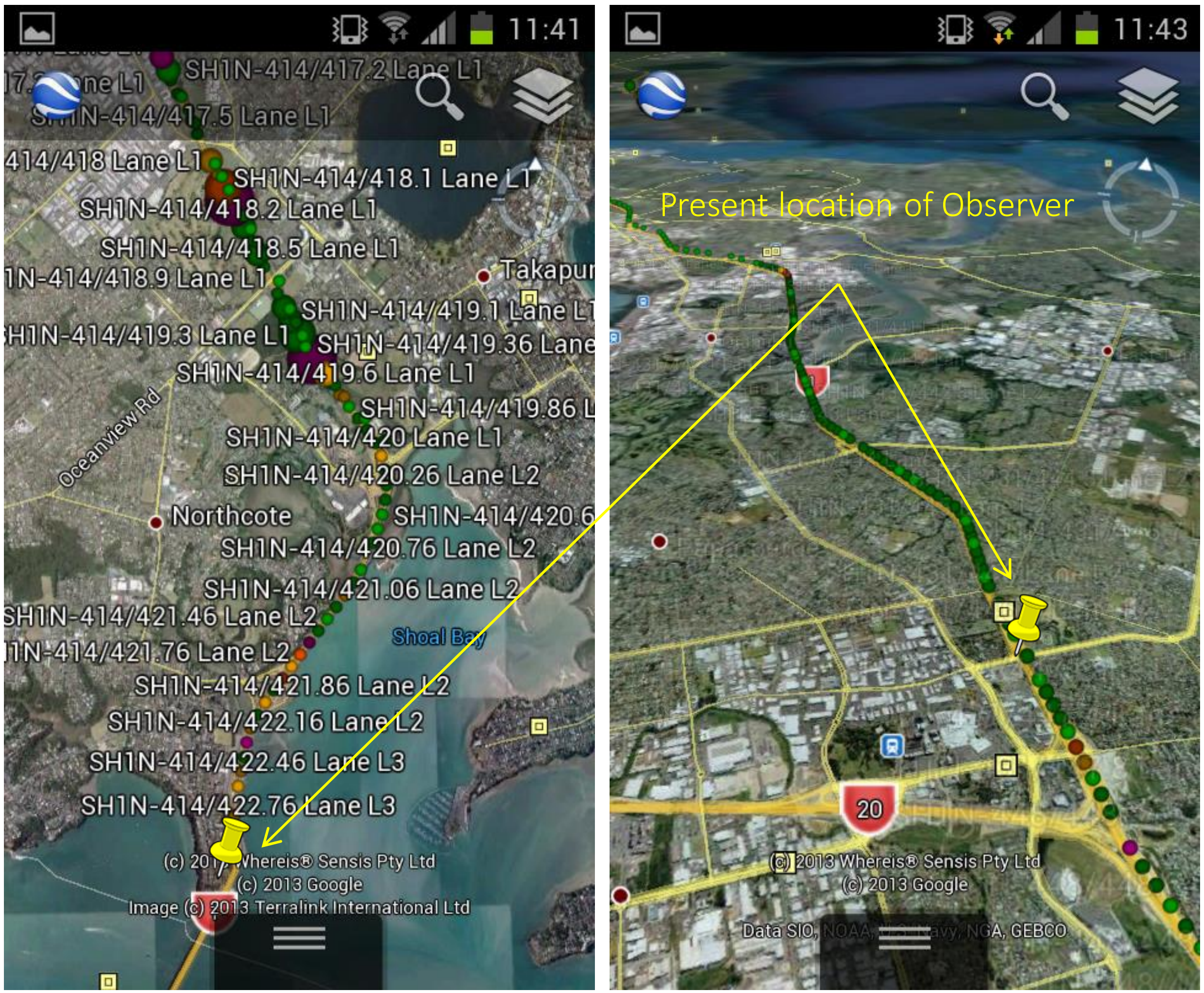


Outcomes

Other parameters of common interest are;

- ✓ the moduli of the various layers
- ✓ the subgrade CBR
- ✓ the subgrade non-linearity exponent (shows potential for drainage improvement),
- ✓ the expected type and depth of remedial treatment necessary to give 25 years life.

Characteristic Parameters
Drainage on Smartphone



Drainage Layer

CBR (%)	10
Design ESA (25 years)	1.76E+07
Subgrade Modulus Exponent	-0.4
Base Layer Modulus (MPa)	1546
Total Life, Rutting* (years)	9
Test Date	22/08/2012
*Note: models are uncalibrated for this site.	

Potential for Improvement in Stiffness (CBR) from Drainage

High Moderate Minor None

Potential Total Rutting Life of Pavement (years)

> 25

(Life beyond 25 years is academic only, but nominal values are still shown for relativity.)

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Characteristic Parameters
Drainage on Smartphone

The degree of non-linearity (n) of the subgrade modulus (detected by the standard FWD test) is frequently an indicator of whether the pavement has “wet feet” and would benefit from improvement of subsoil drainage. If the remaining rutting life is short and n <-0.3 then the maintenance team should check to see if drainage can be improved. The converse is also true so then the team can focus on other solutions to any issue.

Characteristic Parameters
Drainage on Smartphone

SH1N-414/417.2 Lane L1

Drainage Layer

CBR (%)	20	
Design ESA (25 years)	2.20E+06	
Subgrade Modulus Exponent	-0.5	
Base Layer Modulus (MPa)	602	
Total Life, Rutting* (years)	15	
Test Date	21/08/2012	
*Note: models are uncalibrated for this site.		

Potential for Improvement in Stiffness (CBR) from Drainage

High Moderate Minor None

Potential Total Rutting Life of Pavement (years)

> 25 25 > 10 10 > 5 < 5

Directions: To here - From here

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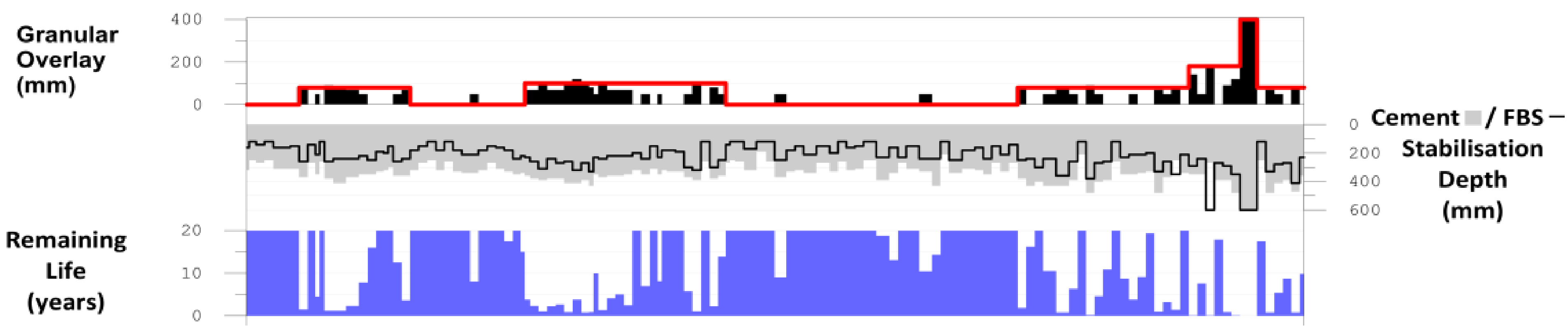
Outcomes – Network Data

Clicking on the Overview icon brings up a summary of the whole treatment length (for rehabilitation with options for depths of cement or foamed bitumen stabilisation, or overlay thicknesses)
Or, the full length of the road (for network management).



PaveState
Conclusion

SH 1-/7.543 Lane R2

Drainage Layer

CBR (%)	8
Design ESA (25 years)	2.73E+07
Subgrade Modulus Exponent	-0.4
Base Layer Modulus (MPa)	437
Total Life, Rutting* (years)	2
Test Date	18/09/2012
*Note: models are uncalibrated for this site.	

Potential for Improvement in Stiffness (CBR) from Drainage

High Moderate Minor None

Potential Total Rutting Life of Pavement (years)

> 25 25 > 10 10 > 5 < 5

Directions: To here - From here

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PaveState 'how to'

- User runs the PaveState software
- selects folder containing pavement data
  - if GPS coordinates were not collected at test time, coordinates are obtained via NZTA web-service.
- selects desired output report format
  - currently drainage or potential pavement life
- selects whether they'd like one output file per road, or one file per network of roads
- hits the run button ("Generate KML")
- chooses where to save output file(s)
- distributes output (e.g. e-mail or web server)
- output then viewed on desired device using Google Earth

PaveState 'how to'

Or

- Obtains relevant kml file from FWD provider (should be available on complimentary basis for any FWD testing carried out in 2013 and onwards)
- Output then viewed on desired device
- Customised for specific users if required

References

[1] *Bailey, Patrick & Jackett NZTA RR 259*

[2] *Arampamoorthy & Patrick NZTA RR 421*

[3] *Salt & Stevens, 2006 (& updates)*

[4] *http://www.NZTA.govt.nz/resources/chipsealing-new-zealand-manual/docs/12-chipseal-failures-and-repairs.pdf*

[5] *Dawson A. 2002 Briefing pavementanalysis.com/papers/documents/pavementsworkshop02/briefing.pdf*

[6] *Dawson A. 2002. Outcomes http://pavementanalysis.com/papers/documents/pavementsworkshop02/outcomes.pdf*

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Peer Review

Comments on Precedence Design based on Mechanistic Analysis

Since the theoretical work of Boussinesq in the 1880's pavement engineers have strived to develop design and analysis methods similar to those used for other engineering structures, where a mathematical model is used to determine the critical stresses and strains, which are then compared to permissible values. Both of these two steps are associated with considerable difficulties. Most pavement materials are more or less granular in nature, responding to external excitements neither as solids nor as liquids, but somewhere in between. Under load they respond with a mixture of elastic, viscous, visco-elastic and plastic deformations, and are prone to temperature, time-hardening, thixotropic, and aging effects. Only recently has numerical computation based on the Distinct Element Method (DEM) become available, but it will still be a while before computers will be efficient enough to treat even semi-realistic problems. Until then pavement engineers will have to rely on approximate methods, mostly based on solid mechanics.

The second step in the engineering analysis requires knowledge of the permissible stresses or strains in the different pavement materials. Several approaches have been followed in order to establish such values, based mostly on 1) laboratory testing on samples of different materials, 2) full scale testing of pavements under controlled conditions, and 3) observation of in situ pavement systems under real traffic loading and real environmental conditions. Each approach has obvious advantages and disadvantages, but may well supplement one another.

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Peer Review

Comments on Precedence Design based on Mechanistic Analysis

The method described in “Pavement Design and Asset Management Using Precedent Performance” is very innovative and makes efficient use of a unique database collected over more than twenty years on New Zealand road pavements. Other large databases of pavement systems or materials testing do exist, such as those collected in the United States, and elsewhere, during the Strategic Highway Research Program (SHRP) which has been going on for more than twenty years, but what makes the New Zealand database unique is the fact that all the deflections measured with the Falling Weight Deflectometer (FWD) have been analysed using the ELMOD (Evaluation of Layer Moduli and Overlay Design program from Dynatest), in order to derive the moduli of the individual layers from an inverse analysis of the deflection data. This back-analysis method allows for non-linear elastic subgrades, that are of crucial importance for pavements with relatively thin bitumen or cement bound layers, typical of New Zealand roads. It has been repeatedly demonstrated that ELMOD provides realistic pavement layer moduli, and predicts the pavement response reasonably well compared to measured response values. For each measured deflection basin, the layer moduli have been determined, based on the thickness of the pavement layers, using a consistent analysis procedure, and stored in the database. The New Zealand database thus contains fundamental materials properties, enabling an analytical modelling of the pavement response and performance, rather than simple analyses based on purely statistical methods. Similar interpretation of the FWD deflection data has not been carried out for any other existing database of similar magnitude. In addition the design traffic of all pavement sections tested, have been determined and associated with each of the analysis points.

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Comments on Precedence Design based on Mechanistic Analysis

The fact that the database contains layer thicknesses and layer moduli, makes it possible to determine the critical stresses and strains in the different pavement layers under a standard axle load, based on mechanistic methods. This pavement response can then be related to the design traffic, and relationships between critical stresses or strains, and the number of load repetitions can be established, based on assumptions of the frequency of pavement rehabilitation measures.

Several examples are given in the paper that clearly demonstrates the oversimplifications of existing design relationships. Of particular importance is the demonstration of the variation of the exponent in the relationship between response and number of load repetitions. The large majority of existing relationships, mostly based on laboratory testing or full scale testing under controlled conditions, assume a constant exponent, but the data based on Precedence Performance clearly demonstrates that this is erroneous; there are large variations in the exponent depending on the traffic level, the types of materials and the material modulus. This information is highly significant for the prevention of overdesign or premature failure.

For a number of pavement sections, where multiple FWD testing sessions have made it possible to establish time series from the database, it has also been feasible to determine the changes in pavement layer moduli as functions of time and traffic loading, and to some extent also of climatic region. Again this has demonstrated that existing assumptions of the development of layer moduli with time and traffic, based mostly on laboratory data, can be rather different from the actual development of the layer moduli, in real pavements under real traffic and climatic conditions. This is of particular importance for foamed bitumen or cement bound materials, but is also of interest to many other pavement m

Peer Review

Comments on Precedence Design based on Mechanistic Analysis

The database of fundamental pavement layer characteristics, established for New Zealand, and the innovative interpretation of the data using Precedence Performance methods, ought to be optimally exploited, and to be continued, if possible with additional data on pavement condition (roughness, rutting, cracking etc.) in order to develop more realistic and reliable methods for prediction of pavement deterioration, as a function of time, loading, environment, and maintenance and rehabilitation actions. If additional time series, comprising other pavement condition parameters than layer moduli, can be established, the method should also open the way for incremental-recursive pavement design and evaluation methods, where the constantly changing parameters such as moduli, climate, loads, damage, aging etc. may be taken into consideration. This will require a concerted effort to keep up the unique New Zealand database on fundamental pavement properties and extending it by relevant data on pavement condition, maintenance and rehabilitation actions, and possibly on some environmental data.

Per Ullidtz
Dynatest International
2014/09/06

Drainage Detail

- For further information, please see GeoSolve's Drainage Project presentation on our website at:
- http://www.pavementanalysis.com/images/presentations/pdf/Drainage_Project-Subsurface_Model_Details.pdf